REINFORCED FLEXIBLE PAVEMENT DESIGN OVER EXPANSIVE AND NON EXPANSIVE CLAY SUBGRADES

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1. INTRODUCTION

In India, about 40 percent of surface soil deposits are covered of clays and 50 percent of them are generally black or brown in colour and expansive in character. The swelling behaviour of the clays is due to prese1nce of highly active mineral, montmorillonite. The problem of damages to structures in expansive soils is not only limited to our country alone, but also present worldwide. In most cases, functionally and economically, it is impossible to bypass these areas or to substitute the clay by a more stable soil. Inevitably a civil engineer has to accept the clayey soil as a foundation bed or a construction material for constructional activities. Several thousand kilometers long road network running over these clayey soils suffer severe distress in the form of heaving and cracking due to alternate wetting and drying in spite of providing large design pavement thickness.

Pradhan Mantri Gram Sadak Yojana (PMGSY) in India is launched on 25th Dec 2000 as a fully funded centrally sponsored scheme to provide all weather road connectivity in rural areas of the country. In the process of development of a country, governments continuously plan to improve road networks by connecting different places in the shortest path. In this process the pavements are to be laid through different subgrade soils. As it is imperative to lay pavement over clay subgrades, there is need for a design methodology which ensures safety of pavements over clay sub grades, with possible reduction in pavement thicknesss.

Pavements are of two types, namely Flexible and Rigid pavements. Generally flexible pavements are preferred to rigid pavements due to their low initial cost, smooth riding surface and easy maintenance. Pavement failures are often noticed in flexible pavements constructed over clay subgrades despite building pavements with large thickness. Low traffic roads are affected by swelling of subgrade whereas the heavy traffic roads are affected by the excessive settlements or shear failures in the edge regions due to softened subgrade during rainy season. The Pavements offer poor riding surface due to volume instability of the subgrade and demand for periodic maintenance after every rainy season.

Hence, there is need for evolving pavement design over clay subgrades which reduces pavement thickness besides improving performance by avoiding overstressing of subgrade in excess of permissible bearing capacity and also controlling swelling. So far geosynthetics are in use to improve the performance of pavements in the form of separators, moisture barriers and capillary cutoffs.The reinforcing action of geosynthetics, particularly geotextiles and geogrids is not much explored. Hence, in the present study, it is intended to formulate design methodologies for reinforced flexible pavements over expansive and non-expansive subgrades using geotextile and geogrid reinforcement.

2. EXISTING PRACTICES OF FLEXIBLE PAVEMENTS AND DEFICIENCIES

Soils those are highly susceptible to volume and strength changes can accelerate the deterioration of the pavement structure in the form of increased cracking, undulating pavement surface and decreased ride quality when combined with truck traffic. The issues of concern in clay subgrades are large pavement thickness, instability, shear failures in shoulder region, undulated pavement surface, deterioration of pavement, stripping of bitumen etc.

The clay subgrades are being treated with various methods to improve the strength and stiffness characteristics to manage construction of pavements. Among the methods employed, soil replacement, soil stabilisation, usage of cushions, moisture barriers are popular. Soil replacement (Snethen, 1979) involves replacement of clay subgrade to the extent of 0.5 to 1.0m by well compacted good quality moorum. The extent of replacement depends on volume stability of soil under moisture variations. However, the method becomes expensive if replacement soil is not locally available. Soil Stabilisation is done by mechanical stabilisation, chemical stabilisation using portland cement, lime, fly ash, etc or by using water proofers. The success of stabilisation mainly depends on uniform mixing and control over mixing of clay with admixtures is difficult in field practice. The moisture barriers are effective in areas where water table is deep. Thus the methods in use at present also have certain limitations and also not that effective as expected.

Among different types of cushions used to serve as capillary cutoffs and to suppress swelling of clay subgrades, Cohesive Non-swelling Soil (CNS) cushions are rated better over expansive soil subgrades as they suppress swelling and improve subgrade to support the pavements (Natarajan and Shanmukha Rao, 1979; Katti, 1979). However it has been reported that CNS cushions become less and less effective with shrink-swell cycles of expansive soils (Subba Rao, 2000). Though CNS cushions control swelling of expansive soils during initial cycles, the combined system of CNS and Expansive soil becomes worse than expansive soil alone.

Patel and Qureshi (1979) have investigated into the failure of single lane roads in expansive clay subgrades and emphasized on the strengthening of shoulder portion as it was responsible for shear failure of the pavements during overtaking of vehicles in rainy season.

In the last three decades geosynthetics have attracted the attention of researchers and highway engineers due to their multifunctional abilities. The majority of studies reviewed indicate appreciable improvement in pavement performance due to use of geosynthetic material in pavement construction. The popular geosynthetics used are geotextiles and geogrids. Particularly geotextiles as a separator are being widely used between sub base and subgrade material to prevent intermixing of subgrade soil and granular base material and to improve life and performance of the pavement. Das (2006) reported that geosynthetics (including geofabrics, geotextiles, geomembranes and geocomposites) play a role in separating materials, reinforcing, filtering, draining and/or serving as moisture barriers. Zornberg and Gupta (2009) reported that geosynthetic reinforced subgrade or base material provides lateral restraint (minimizing spread), tensile membrane support and increases the bearing capacity. Zornberg et al.(2008) reported their findings of field evaluation of 35 pavement projects over swelling clays in the USA (Forth Worth to Dallas) that were experiencing cracking. It is observed that the geosynthetic reinforcement prevented the development of longitudinal cracks. Further, it is noticed that the cracks are relocated beyond the reinforced area. The junction efficiency of geogrid is observed to play large role in performance of the grid in crack propagation control.

Extended service lives for pavement sections with geogrids compared to similar sections without geogrids has been reported by various researchers (Al-Qadi et al. 1997, Barksdale et al. 1989, Cancelli et al. 1996, Collin et al. 1996, Haas et al. 1988, Miuraet al. 1990, Perkins et al. 1997a/b, and Webster 1993). Though use of geosynthetic materials are used in pavement construction, the design procedures are either for unpaved roads or empirical. The methods are summarized below.

3.0 REVIEW OF EXISTING REINFORCED PAVEMENT METHODS

Giroud and Noiray (1985) proposed a design methodology taking into consideration the membrane effect of geotextile and allowance to traffic. In his analysis he equated the maximum pressure on subgrade to ultimate bearing capacity. The theory does not account for the velocity of vehicles, loads and suits only to unpaved roads. The design methodology is based on a total vertical stress at subgrade level, which leads to higher settlements in soft clays. So the theory should not be used in paved roads where surface settlement should not exceed 40mm or less.

Koerner Method (1986) involves conducting CBR test on CBR specimen with soil and aggregates half filled. The test is to be done up to 5 cm penetration level. CBR test is also done on specimen with geotextile held in position at interface of soil and aggregate. The reinforcement ratios, defined as load resisted by unreinforced and unreinforced specimen are calculated at different penetration levels. Modified CBR value is determined as Maximum reinforcement ratio x actual CBR value of soil. The design thickness of reinforced flexible pavement is determined using modified US army Corps of Engineers Formula However, the design is based on small scale load penetration test and needs verification in the field.

Bender and Barenberg (1978) related allowable stress on subgrade to ultimate bearing capacity without significant rutting (less than 5 cm). Design curves have been developed using elastic stress distribution theory for rut depth of 10 cm and low traffic volume (N<100) using low and moderate modulus fabrics for different wheel loads (22 kN– 89 kN) and contact pressures of 345 to 552 kPa (Bender and Barenberg, 1978). These curves can not be directly used for Indian roads as allowable rut depth is less than 10 cm as assumed (Venkatappa Rao, 1998).

SBC Method of Approach

Satyanarayana Reddy (2002) proposed a design methodology for reinforced flexible pavement based on safe bearing capacity concept rather than CBR method to ensure safety against risk of shear failure. The design was based on membrane action of geotextile with due consideration of wheel load stresses and swell control of subgrade. However, the design is not validated from elastic layer theory for stress at subgrade level. Also the method is to be validated and needs verification from field test track studies.

Keeping in view of the above literature the deficiencies observed with regard to reinforced flexible pavements are as follows.

- There is no established validated procedure for design of reinforced flexible pavement over clay subgrades in general and expansive clays in particular.
- The concept of membrane action of geotextile reinforcement requires further study.
- Usage of geotextile held in position at subgrade, for swell control was not given much attention.
- None of the papers reported reinforced mattress approach using geogrid reinforcement to spread the loads over wide area.
- Less work was done on performance study of laid reinforced test tracks with geosynthetic reinforcement in clay subgrades in general and expansive soils in particular.

4.0 NEED FOR THE PRESENT STUDY

For development any country a well connected good quality road network is necessary. Inevitably this has to pass through clay subgrade soils and hence, it is essential to develop a performance reinforced design methodology. In non expansive clay subgrades

the large ruts and associated undulations in pavements can be prevented if wheel load is dispersed over wider area using basal reinforcement as stiffener. In expansive clay subgrade, not only overstressing of subgrade shall be avoided, but also the swelling of subgrade should be also controlled to have a pavement of good riding surface. As no such pavement design methods are available, in the present study, design methodologies are formulated for reinforced flexible pavement design over non expansive and expansive clay subgrades ensuring safety against swell, shear failure and settlement failure risks. The performance of the sections designed based on formulated designs is assessed for test track studies. Control sections based on conventional CBR method have been also laid to assess the relative assessment of the reinforced sections. The design formulation over expansive clay is proposed based on membrane action of geotextiles held in position at subgrade. For non swelling clay, the design is developed based on the concept of "Reinforced Soil Mattress".

5. RESEARCH METHODOLOGY

The research work has been divided in to four stages and is explained through flow chart shown in Fig. 1.

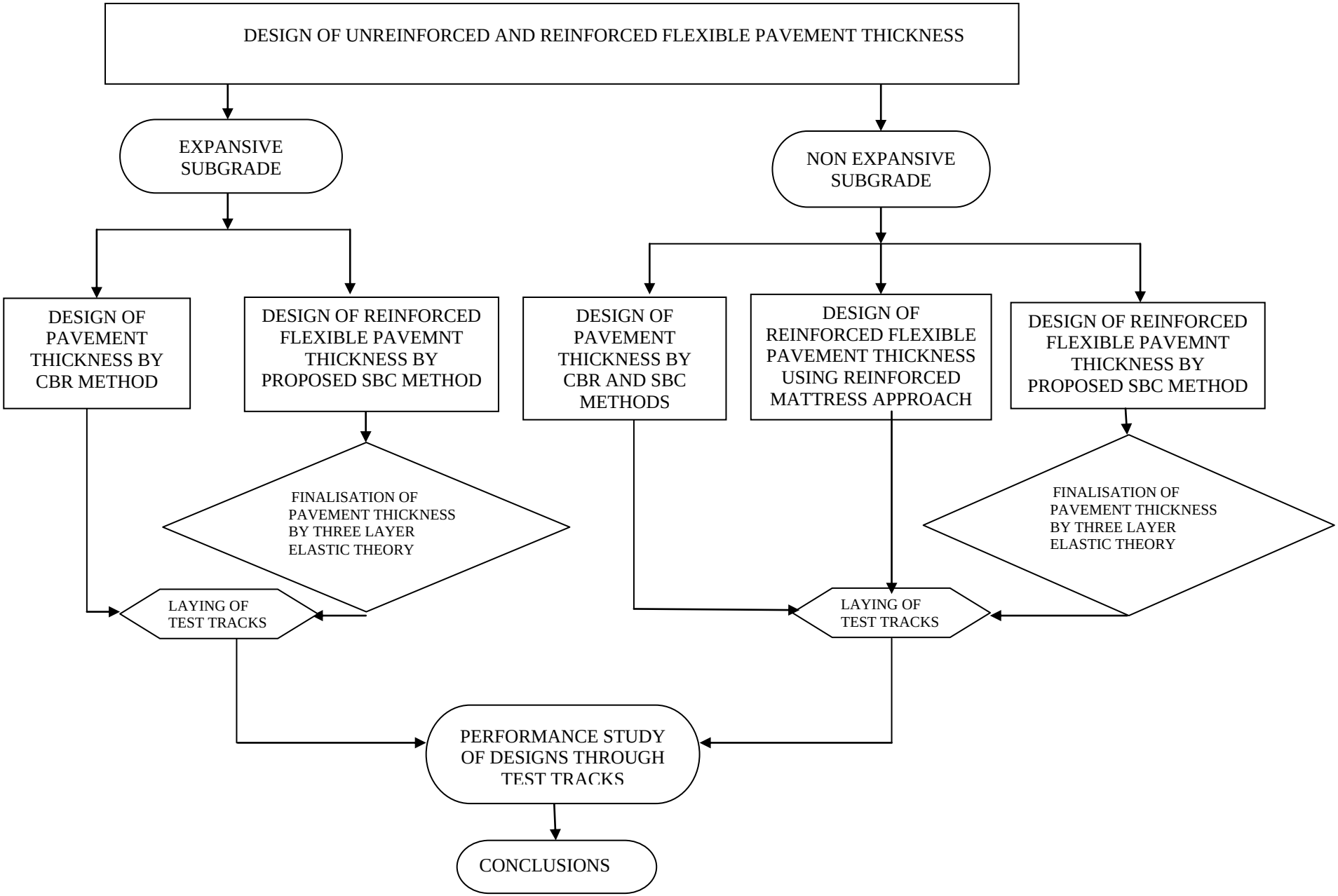
DESIGN OF UNREINFORCED AND REINFORCED FLEXIBLE PAVEMENT THICKNESS
EXPANSIVE SUBGRADE
NON EXPANSIVE SUBGRADE
DESIGN OF PAVEMENT THICKNESS BY CBR METHOD
DESIGN OF REINFORCED FLEXIBLE PAVEMNT THICKNESS BY PROPOSED SBC METHOD
DESIGN OF PAVEMENT THICKNESS BY CBR AND SBC METHODS
DESIGN OF REINFORCED FLEXIBLE PAVEMENT THICKNESS USING REINFORCED MATTRESS APPROACH
DESIGN OF REINFORCED FLEXIBLE PAVEMNT THICKNESS BY PROPOSED SBC METHOD
FINALISATION OF PAVEMENT THICKNESS BY THREE LAYER ELASTIC THEORY
FINALISATION OF PAVEMENT THICKNESS BY THREE LAYER ELASTIC THEORY
LAYING OF TEST TRACKS
LAYING OF TEST TRACKS
PERFORMANCE STUDY OF DESIGNS THROUGH TEST TRACKS
CONCLUSIONS

Figure 1 Flow chart of proposed Research Methodology

The **first stage** of the work has been devoted to formulate a design methodology for reinforced flexible pavement over expansive clay subgrade.
This has been done through

- Evaluation of CBR method of flexible pavement design for safety against risk of shear failure of subgrade soil.

- Placement of geotextile reinforcement at subgrade level and exploring its membrane action for resisting wheel loads safely and controlling the swelling of subgrades.

As there will be risk of shear failure in clayey soils under applied loads, it is preferable to check adequacy of the design pavement thickness from safe bearing capacity of soil subgrade also. The safe bearing capacity method of design proposed in the study, involves determination of pavement thickness by equating the vertical stress at subgrade due to dispersion of wheel load and overburden to the allowable bearing capacity of subgrade soil. The considerations that are involved in safe bearing capacity based design methodology as proved by Satyanarayana Reddy (2005) are given below.

1. The allowable bearing capacity of soil subgrade is taken as 80 percent of safe bearing capacity value under static loading.

2. The loading due to moving vehicles in heavy traffic roads over saturated clay subgrades is equivalent to strip load since in saturated condition the excess pore water pressures do not get dissipated quickly.

3. The load bearing mechanism of pavement component layers is due to passive resistance offered by material of the layers under applied wheel loads and so 2V:1H load dispersion is valid through the flexible pavement layers.

4. The legal axle load is 10.2 t and wheel configuration is dual with contact pressure of 5.62 kg/cm^2.

5. The shape of contact area of tyre with pavement is rectangular with two semi circular areas at the ends.

After having checked the safety of pavement design over clayey subgrades for shear failure, the reinforced flexible pavement design procedure is formulated as the required values of thickness are high. The additional considerations in the design procedure of reinforced flexible pavement design are

- Reinforcement is held in position due to frictional resistance mobilized from around and through side anchorage and thus utilizes its membrane action.
- Deformation of fabric is due to shear displacement initially induced and later stabilizes due to mobilized membrane action.
- The stress induced on subgrade due to membrane action of flexible reinforcement is 0.8 times safe bearing capacity of soil.

As the geometry of deformed fabric shape at subgrade influences design requirement of reinforcing fabric it is essential to adopt appropriate deformed fabric shape for design, based on earlier research by Satyanarayana Reddy (2003) it was established that in soft subgrades, uniform deformation is justifiable. Based on Binquet and Lee (1975) theory, in the present study the deformation of fabric at subgrade under dispersed wheel load is taken to be uniform.

Swell is significant influencing factor of performance of pavements over expansive soils. Hence it is desirable to have design methodology over expansive soil subgrade ensuring safety against ‘swell’. The swell control of expansive subgrade is influenced by type of cushion material (sub base) and reinforcing fabric. The swell control has been studied through reduction in percentage swell of expansive soil with granular cushion namely moorum and without reinforcing fabrics at the interface. The reinforcing fabrics used in the study are woven geotextiles.

As geotextile is flexible and mobilizes its strength only upon straining, it is not possible to control entire swelling of subgrades. Hence, the requirement of tensile strength of fabric for different allowable permissible swells has been worked out based on free body

diagram of geotextile fabric in between anchorage trenches. To cut down the requirement on stiffness of fabric it is proposed to anchor geotextile.

The vertical and shear stresses induced at the level of subgrade under varying thicknesses have been evaluated using Peattie stress-strain factors for three layer systems (Highway Research Board Bulletin 342, 1962) using the modulus of elasticity values of WMM base, Sub base and subgrade materials calculated based on measured Field CBR values from test tracks laid using Relations suggested by IRC 37-2001.

The **second stage** is planned to formulate a design methodology for Reinforced Flexible pavement over non expansive clay subgrade using wheel load approach as explained in first stage and also based on reinforced mattress approach. As swelling is insignificant, no restraining of subgrade is required. The performance of the road and undulating pavement surfaces can be reduced by spreading the load over a larger area. Hence, the reinforced soil mattress concept is applied to stiffen the sub base layer using geogrid reinforcement in flexible pavement design.

An intermediate compressible clay subgrade has been chosen for the proposed methodology. It is proposed to use foundation mattress at the base to increase load dispersion width and reducing the applied load intensity on the sub soil. This concept of reinforced soil mattress is extended to stiffen the sub base layer of pavement to spread the load uniformly on to subgrade over a large area.

The design of sub base foundation mattress is done by considering single lane pavement and taking 1.2 m wide shoulder. It is proposed to use granular sub base as per MORTH specifications and extend it into shoulder portion also. For critical loading, two trucks have been taken side by side with a minimum clearance of 0.2 m. The width of each truck has been taken as 2.5 m.

The contact pressure at subgrade is determined by considering the stiffening action of sub base. The reinforcement is designed in sub base for maximum bending moment by taking cover to geogrid reinforcement as 50 mm on either side. The required tensile strength (T) of reinforcement is calculated using the relation

$$T = \frac{Max.B.M}{d}$$

Where, d is effective depth of sub base layer.

The **Third** stage of methodology is devoted to finalize design thickness of pavement for laying tracks over expansive and non expansive subgrades. The reinforced and conventional unreinforced flexible pavement test tracks have been laid for performance appraisal against swelling of expansive subgrade (CH). Also the geogrid mattress reinforced test track, geotextile reinforced test track and conventional unreinforced flexible pavement test track have been laid on a clayey soil of intermediate compressibility (CI) to observe relative performance. The reduced levels of surface at left, centre and right locations of test track sections have been determined in different seasons and average values of reduced levels have been taken for study.

Reduced levels of surface of unreinforced and reinforced test tracks of expansive clay (CH) subgrade.

Period	Location	Unreinforced Test track	Geotextile Reinforced Test track
Nov' 11	L	99.879	99.680
	C	99.952	99.754
	R	99.821	99.613
April' 12	L	99.809	99.664
	C	99.891	99.741
	R	99.759	99.596
Nov' 12	L	99.886	99.684
	C	99.956	99.757
	R	99.824	99.616

Reduced levels of surface of unreinforced and reinforced test tracks of clay of intermediate compressibility (CI) subgrade.

Period	Location	Unreinforced Test track	Geogrid Reinforced Test track	Geotextile Reinforced Test track
Nov' 11	L	99.713	99.573	99.623
	C	99.729	99.609	99.641
	R	99.749	99.649	99.661
April' 12	L	99.674	99.559	99.602
	C	99.691	99.560	99.621
	R	99.706	99.556	99.639
Nov' 12	L	99.711	99.568	99.619
	C	99.726	99.570	99.635
	R	99.744	99.572	99.655

In the **Fourth** stage of the work, comparative study of performance of reinforced flexible pavement sections over expansive and non expansive clay subgrades under study over unreinforced sections is made. Also comparison of performance is done among test tracks laid using Geogrid, Geotextile and conventional approach on non expansive clay subgrade (clay of intermediate compressibility under the study).

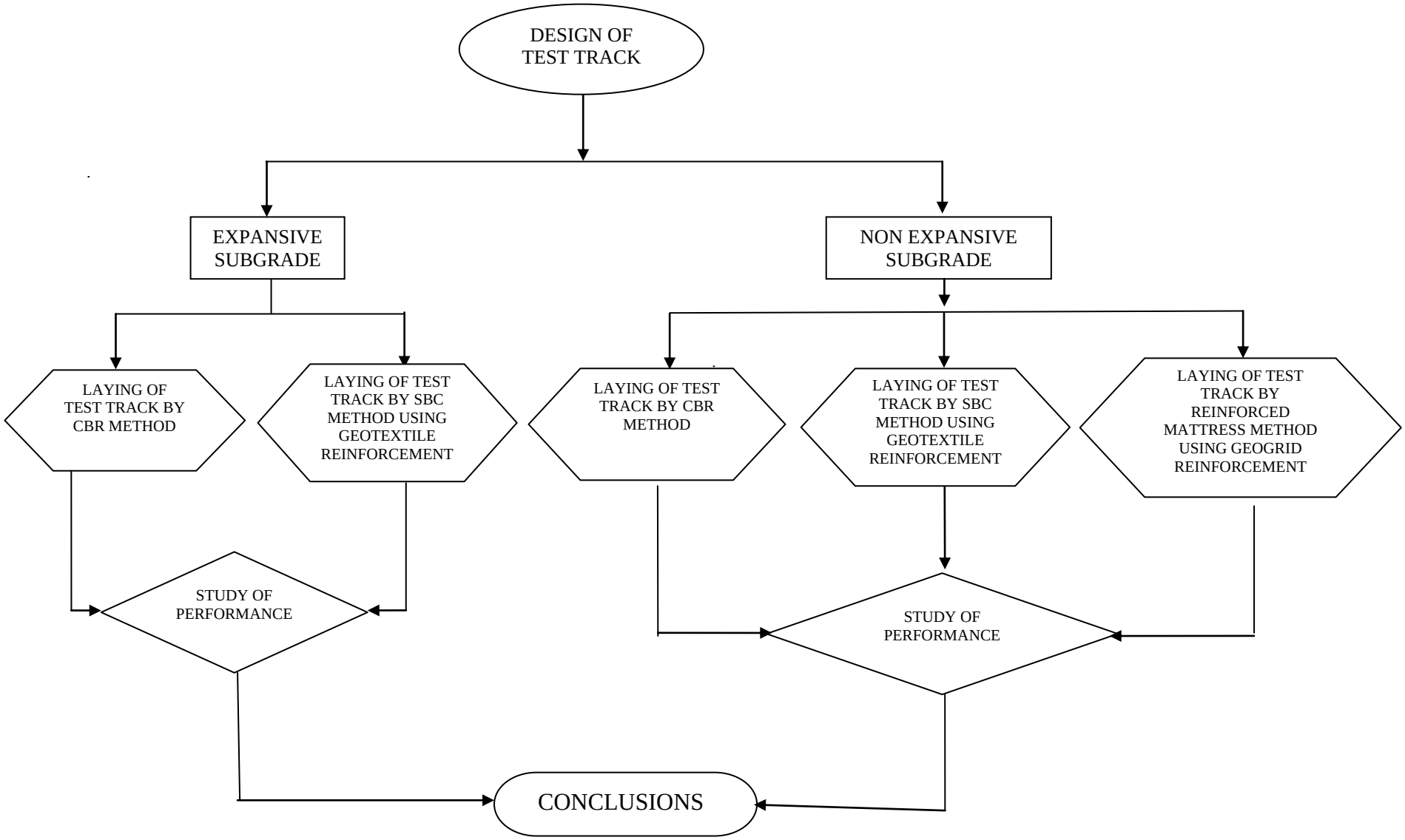
DESIGN OF TEST TRACK
EXPANSIVE SUBGRADE
NON EXPANSIVE SUBGRADE
LAYING OF TEST TRACK BY CBR METHOD
LAYING OF TEST TRACK BY SBC METHOD USING GEOTEXTILE REINFORCEMENT
LAYING OF TEST TRACK BY CBR METHOD
LAYING OF TEST TRACK BY SBC METHOD USING GEOTEXTILE REINFORCEMENT
LAYING OF TEST TRACK BY REINFORCED MATTRESS METHOD USING GEOGRID REINFORCEMENT
STUDY OF PERFORMANCE
STUDY OF PERFORMANCE
CONCLUSIONS

Figure 2. Flow chart showing study of test tracks

6. CONCLUSIONS

1. The proposed method of design for reinforced flexible pavements using flexible reinforcement with uniform deformation of fabric at subgrade level with elliptical heaving on either sides yields reasonable stiffness for reinforcing fabric over soft clay subgrades.

2. The design thickness finalized from the present research ensures safety against overstressing of subgrade as it is validated from Peattie three layer elastic theory.

3. Use of Geotextile as reinforcement at expansive subgrade under study reduced the design thickness of the pavement by about 25 percent.

4. The geotextile held in position by anchorage in longitudinal trenches results in control of additional swell (20 percent in the present study) provided the sub base moorum controls some swell (65 percent in the study) initially due to its cushion action.

5. Shoulder region also gets strengthened due to geotextile anchorage and hence, shear failures in edge region of pavements can be avoided.

6. Transforming the sub base layer as reinforced mattress helps the CI soil in spreading the loads over a larger area and thus avoids the problem of shear failure.

7. Granular sub bases are to be used in flexible pavements over clay subgrades so that they can be transformed as foundation mattress for safe and uniform transfer of stress to subgrade.

8. The sub base should be provided by two layers of reinforcement at top and bottom levels of the layer as the developed bending moments change sign across the width of the mattress.

9. Sub base foundation mattress extending into shoulder portion strengthens the shoulder region and avoids failures during overtaking of vehicles.

10. Test track studies with geogrid reinforcement reveals that pavement with geogrid reinforcement at subgrade has better performance in controlling penetration of sub base material.

11. Use of geogrid reinforcement helps in reducing the settlement by about 60 percent.

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